Nuclear Plant Risk Assessment Notes

This presentation addresses the nuclear power plant risk assessment process.

Slide 2 – hazard and risk

- understanding of risk, measurements of risk and even definition of risk vary in different business arenas
- in safety field, risk typically defined as likelihood and severity of hazardous events
- safety risks controlled using techniques of risk management

Slide 3 – principles of risk management

- principles of risk management must be acknowledged in any discussion of risk

Slide 4 – principles of risk management (cont.)

- finite probability of occurrence for all risks an important risk management principle to understand
- no such thing as zero risk and risk probabilities should not be viewed as absolute

Slide 5 – risk management maxim

- one other aspect of risk management that must be acknowledged in any discussion of risk
- risk discussions oftentimes elicit more emotional reactions than rational thinking
- classical risk management consists of insurance, where transfer of risk shifts responsibility for losses from one party to another in return for payment
- technical risk management requires technical solutions to risk issues and should never result in transfer of risk to some other setting
- often politics drives risk decisions
  - space shuttle Challenger accident was result of politically-driven risk decision
  - underutilization of nuclear power is result of many politically-driven decisions regarding potential nuclear risks

Slide 7 – risk models

- when risk information communicated to public, seldom addressed is robustness of risk model from which risk information derived

Slide 8 – theoretical risk – LNT model

- example of theoretical risk model is seriously flawed linear no-threshold (LNT) dose-response model used to predict radiation-

induced cancer incidence and mortality from low dose ionizing radiation exposures

- created by linearly extrapolating data from very high ionizing radiation exposures of Japanese atomic bomb survivors to zero dose, with assumption that any radiation exposure increases cancer risk
- no verifiable cancer incidence and mortality data to support predicted deaths from low-dose ionizing radiation exposures

Slide 9 – data-based risk – U.S. motor vehicle fatalities

- example of data-based risk model is motor vehicle accident fatality model based on discrete events that can be confirmed to have taken place and which can be confirmed to have caused a death
- actual number of motor vehicle deaths each year plotted to create model from which valid information can be discerned (e.g., mortality trends)

Slide 10 – unacceptable transfer of risk

- example of what can happen when linear no-threshold dose-response model used to drive decisions regarding *potential* health consequences from low dose radiation exposures

Slide 13 – example qualitative risk matrix

- as illustrated in graphic, based on combination of likelihood of occurrence and potential consequences, various risks determined to be low, moderate, high, and extreme

Slide 14 – example quantitative risk matrix

- here also, based on combination of likelihood of occurrence and potential consequences, various risks determined to be low, moderate, high, and extreme
- some extreme risks may be so costly to remediate that purchasing insurance becomes least objectionable decision-making option

Slide 19 – nuclear safest energy of all graphic

- graphic of deaths per terawatt-hour of electricity generation includes fatalities from entire energy resource lifecycle
- also included are **estimated** deaths due to air pollution from burning coal, oil, and natural gas
- at end of 2021, worldwide cumulative reactor operating experience amounted to over 19,000 reactor-years – have much more electricity-generating experience with nuclear energy than with wind and solar energy resources, with far fewer lifecycle fatalities

Slide 21 – example event tree

- event tree defines possible sequences of events based on initiating event and subsequent success or failure of event-mitigating systems and functions
- want to determine end state failure probabilities for purpose of deciding if mitigating actions are necessary to further reduce end state failure probability
- if event failure data not available, then fault tree construction necessary to determine failure probability for that event

Slide 22 – event tree-fault tree relationship

- as shown in graphic, fault tree constructed to determine probability of reserve parachute failure to open for skydiving event tree

Slide 23 – example fault tree

- fault tree defines various ways in which failure event can occur based on system, subsystem, and equipment failures, as well as human errors that could result in failure event
- Boolean logic operators shown in graphic define dependence of hardware failures and human errors required to obtain top fault tree event
- basic events, for which no further logic development required identified with circles as shown in graphic

Slide 24 – Boolean algebra

- graphic illustrates logic of Boolean operators most commonly used in fault trees
- AND operator – all inputs must be present to produce an output
- NOT operator – an input, or lack thereof, produces its opposite at output
- OR operator – any input will produce an output

Slide 25 – solving PRA model

- reducing fault tree logic produces cutsets
- cutset is distinct path of failure leading from basic events to top undesired fault tree event taking into account AND and OR logic operators of fault tree
- many fault tree cutsets typically identified, but not all are unique
- failure probability (or frequency) of undesired end state derived from cutsets and failure probabilities of basic events therein

Slide 28 – sources of PRA input data

- Common-Cause Failure Database and Analysis System contains equipment failure data obtained from searches of Reactor Licensee Event Reports, Nuclear Plant Reliability Data System failure reports, and Equipment Performance and Information Exchange failure reports

Slide 29 – PRA accident consequences

- use of LNT and collective-dose models for determining potential accident public health consequences renders PRA risks unrealistically high, thereby promoting unwarranted public fear

Slide 31 – DBA general event characterization

- 9 categories of design basis accidents that must be addressed in plant's design basis documentation
- 5 events shown in slide associated with reactor's heat removal capability

Slide 32 – DBA general event characterization (cont.)

- first two events associated with uncontrolled increases in reactor power
- third event involves uncontrolled release of radioactive material

Slide 33 - DBA general event characterization (cont.)

- last design basis accident category is external events, which also includes terrorist attacks

Slide 34 – PRA risk acceptance

- USNRC specifies design, construction, and operating rules and regulations that must be met for nuclear power plant owner to obtain operating license
- purpose of plant's design basis documentation to show how plant complies with those rules and regulations

Slide 35 – NRC safety goals for operating reactors

- with specified core damage and large early release frequencies, plant risk assessments can show compliance with NRC safety goals
- origin of core damage frequency
  - International Commission on Radiological Protection (ICRP) adopted risk-based approach to setting radiation protection standards in 1977
  - approach required average incremental risk of death from radiation exposure to workers in radiation industries be no larger than average incremental risk of death from traumatic injuries to workers in "safe" industries
  - incremental risk of death in "safe" industries determined to be one in ten thousand, or 10^{-4} per year

Slide 36 – NRC safety goals for new reactors

- new safety goals more than just exercise in sharpening the pencil
- dictates higher quality standards for safety-related structures, systems, and components, which translates to higher capital cost for new nuclear power plants

Slide 37 – assessment of NPP PRA realism

- TMI and Fukushima accidents revealed that PRA accident consequence predictions significantly more severe than observed

Slide 38 – state-of-the-art reactor consequence analysis

- NRC study begun in 2007 designed to take advantage of many decades-worth of reactor testing, experience, analysis and risk assessment
- exhaustive study updates consequence predictions from reports of studies completed several decades ago

Slide 39 – effect of excessive PRA conservatism

- statements from State-of-the-Art Reactor Consequence Analysis report support conclusion that U.S. nuclear reactors are safe, pose no threat to people who live near them, even in event of severe accident, and are unnecessarily burdened by excessive regulations

Slide 41 – nuclear risk communication – the good, the bad, and the ugly (cont.)

- with respect to educating American public about nuclear science, professional organizations like American Nuclear Society and Health Physics Society, and advocacy organizations like Nuclear Energy Institute clearly haven't been effective in counteracting anti-nuclear propaganda

Slide 42 – nuclear risk communication – the good, the bad, and the ugly (cont.)

- trust very difficult to regain once lost
- Russian attempted coverup of Chernobyl accident led to false assertions of increased cancer incidence/mortality in nearby human populations and genetic mutations in local wildlife
- Japanese radiophobia regarding low level radiation releases from Fukushima accident led to unwarranted government-mandated evacuations

Slide 44 - nuclear risk communication – the good, the bad, and the ugly (cont.)

- irrational movements in public education didn't occur overnight
- movements ideologically-driven and have been developing since latter half of 20th century
- now witnessing acceleration of their fulfillment
- science community must assume responsibility for letting this happen because we didn't have courage to vigorously oppose corruption of genuine science from beginning
- furthermore, too many people in science community have sacrificed their integrity for both public and private funding of politically-motivated junk science

Slide 45 – effect of emotions and groupthink in communications

- if there is nothing to temper one's natural instincts during times of stress and fear, then emotions and groupthink tend to be drivers of behavior

Slide 46 – public unawareness and indifference

- while public education is uphill battle, it’s a battle we cannot afford to lose if we want to guarantee abundant, affordable, and reliable energy for future generations of Americans
- Vaclav Smil is Czech-Canadian scientist and policy analyst; Distinguished Professor Emeritus in the Faculty of Environment at the University of Manitoba in Winnipeg, Canada whose interdisciplinary research interests encompass energy, environmental, food, population, economic, historical and public policy studies

Slide 48 – beyond design basis accidents

- accidents outside realm of what plant designed to withstand
- difficult to predict either because have never occurred or because of extreme rarity

Slide 49 – BDBA evaluation

- while no formal analysis required, BDBA sequences given sufficient attention in nuclear plant’s safety documentation to show understanding of how plant design affected by BDBA occurrence

Slide 50 – BDBA risk acceptance

- bottom line is, sometimes you can’t have your cake and eat it too

Slide 51 – beyond design basis accident?

- Calvin & Hobbes cartoon is humorous exaggeration of BDBA scenario, but it raises important question; where to draw line on BDBA scenarios